TAILORED SYSTEMS ARCHITECTURE FOR DESIGN OF SPACE SCIENCE AND TECHNOLOGY MISSIONS USING DoDAF V2.0

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Abstract

The use of systems architecture, following a set of integrated descriptions from an architecture framework, has been well codified in Department of Defense acquisition and systems engineering. However, in the Space Science and Technology (S&T) community, this guidance and practice is not commonly adopted. This paper outlines an approach to leverage the changes made in DoD Architecture Framework 2.0 (DoDAF2.0), and the renewed emphasis on data and support to acquisition decision analysis. After decomposing the Space S&T design lifecycle into phases, design milestones and activities using process models, a set of DoDAF prescribed and Fit-for-Purpose views are constructed into a reference implementation of a system architecture. This approach attempts to make DoDAF2.0 more relevant and integrated with S&T missions, the decisions that are encountered, and facilitates re-use with existing documentation.

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Nicholas Merski

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TAILORED SYSTEMS ARCHITECTURE FOR DESIGN OF SPACE SCIENCE AND TECHNOLOGY MISSIONS USING DoDAF V2.0

I. Introduction

Within the Department of Defense the use of systems architecture has become a necessary activity within systems development. In the Space Science and Technology (S&T) forum, where guidance on whether to use and implement architecture permits latitudes and where an urge to field the system and validate a capability is paramount, documentation and other systems engineering practices may receive less attention than they deserve. Nonetheless, the systems under development are a complex system of systems and similar needs, goal and motivations that were impetus for the system architecting mandates for larger programs do exist.

Given the focus on rapid development and transition, if a system architecture framework could be developed and used to increase visibility within the design, and was a useful tool for stakeholders and developers alike and was well aligned with the design effort, the reference model could serve as a valuable tool throughout the development.

1.1 Problem Statement

As the goals for space technology demonstrations become more ambitious, the schedule and budget expectations are commensurately challenging. Thus, as developmental systems are acquired; in many cases the focus is to minimize waste by

eliminating any excess. Given the relatively finite nature of space experimental and technology demonstration missions and the absence of mandates, a formal system architecting model is typically not developed or maintained.

However, the development and integration of innovative space technology is a technically complex environment that requires multiple systems operating in conjunction with each other to function correctly. Additionally many S&T missions are "non" standard solutions. Designs are frequently an amalgamation of previous systems, COTS and new engineering thus adding complexity from an interface standpoint.

Given this complex development environment, any tool or process that promotes insight into systems relationships and aids the maturation of system development could be a useful asset supporting decision making and adding structure for the developer and stakeholder. However, a common criticism of system architectures and the DoDAF model is that they do not support the aforementioned objectives for an architecture.

Instead, the common perception is that architecting models and products are secondary end products developed to satisfy regulations. This split between system architecting goals and perceptions beg the following question. How is the need for architecture, and the information it provides, balanced with the challenge to avoid superfluous overhead?

The Department of Defense has tried to address the classes of concerns in the release of DoDAF version 2.0. The recent revisions place a strong emphasis on having the stakeholders define the objectives and implement the model to service those

objectives. "Architecture scoping must facilitate alignment with, and support the decision-making process and ultimately mission outcomes and objectives." (1 p. 28)

Using the revised guidance and processes from DoDAF 2.0 this research will offer concepts for a potential implementation of the DoDAF in a reference model that is aligned with purpose, objectives, and roles for architecture in the design of space S&T system acquisition. Additionally, it will attempt to provide some validation of the model offerings through historical examples demonstrating the relevance of these model(s) within the design of a space system.

1.2 Research Objectives

The objective of this research is to investigate the ability to tailor the DoDAF 2.0 model for a role that effectively supports the design of space technology demonstration missions. This will be accomplished by first identifying common developmental issues, decisions and critical information required to support a space S&T design and development.   Then using this insight, objectives and roles for a systems architecture will be developed. Finally, views with an accompanying maturity model that is aligned with design and acquisition timelines for space systems will be offered for potential application that would be consistent with DoDAF 2.0 guidance.

1.3 Research/ Investigative Questions

As stated above, the goal of this work is to develop a tailored architecture using DoDAF 2.0 guidance. In order to effectively accomplish this certain questions regarding the applicability of architecting must be investigated.   Initially, broad questions resolving

architecture scope such as, “how systems architecture could be used as a tool to aid stakeholders in space system development or management” must be posed to help frame the purpose of the effort. These inquiries will be followed with more detailed inquiries regarding decision processes and information that may be a relevant part of creating a useful tool for the stakeholder. Finally, implementation questions such as, “how architecture could be implemented in a cost and schedule effective fashion, to minimize the overhead associated with the activity” will be addressed to investigate streamlined methods for application.

1.4 Methodology

The initials steps of this effort were spent developing an understanding of current state of architecture within the DoD in order to refine understanding of architecture use and value. This was accomplished by gathering data on the DoDAF framework implementation prior to version 2.0. This knowledge was expanded by developing a broad understanding of the shortcomings with the implementation of current system architecture efforts and as the solutions that are being suggested by the systems engineering community. Following this effort, a significant amount of time was spent with the revised DoDAF framework (V2.0) in order to develop a comprehensive understanding of how the vision and implementation have changed.An understanding of version 2.0 was essential in the next step of developing questions for subject matter expert assessment of system architectures. In this phase, data was gathered from various stakeholder groups associated with satellite development to answer questions regarding system development. The questions were oriented to get a better understanding of how

information or the lack thereof affects program decision making. Additionally, individuals were asked to identify project information that is critical for decision making that is not formally required or tracked but may play a critical role in decision making throughout the development. This information was used to develop conclusions regarding the roles architecture may have in a space S&T development environment as well as inputs for the types of models that would be useful for a development.

After notional roles and purposes for S&T architecture were identified, the next task was to develop a streamlined systems architecture framework using the DoDAF 2.0 model. This effort began by first investigating standard program deliverables for a development and evaluating both the information contained within and how these products and tools contribute to decision making. This information was then synthesized with the stakeholder inputs to help develop a notion of what views and models would be relevant given both the goals mentioned above as well as the inputs from subject matter experts.

After the notional set of views and models were developed, attention was given to looking at how the models could be implemented easily within the existing development in order to minimize overhead. One of the major efforts at this point was developing a reference model for maturing the systems architecture views. The first step in this effort was highlighting possible uses for architecture views to assist decision making throughout the development timeline. Once these opportunities were identified, the

evolution of architecture views was carefully considered in order to align model and its information with relevant activities in the development.

The final step in this effort was to develop conclusions regarding the effort that was conducted and attempt to understand the positive impact this effort could have on a development. This was done by looking at previous development and discussing how the presence of architecture may have helped avert issues encountered and suggesting way that the architecture could be applied to gain valuable data regarding applicability.

1.5 Assumptions/Limitations

This effort suggests methods and processes for creating an architecture that is relevant for a focused area namely the design of developmental space systems. The relevance of the models proposed are inferred through the informal interviews regarding lessons learned, developmental issues encountered, and processes previously encountered in development.

1.6 Research Implications

The S&T community has the role not only to demonstrate the feasibility of a technology, but to assist the larger acquisition community by developing a knowledge base that can be leveraged for an operational acquisition. By developing a construct where critical system design information is more accessible and timelier, one may facilitate the transition of a technology from the "laboratory to the field" by expediting the development itself as well as the broader technology maturity processes.

II. Literature Review

2.1 Current State of DoD Architecting

The use of system architectures within the DoD acquisition is a well established and practice at this point in time. The application of system architecting has been expanded well beyond its inception in the 1990's within the Command, Control, Communications, Computers, Surveillance and Intelligence Architecture Framework (C4ISRAF). The guidance initially provided within the DoD 5000 series documentation (2) in 2003 and refined in both joint and component instructions has largely required the use of systems architectures throughout the defense enterprise.

Although guidance to develop system architectures in conjunction with defense acquisitions is well understood, the roles, purpose and processes for creating, maturing and using a systems architecture among systems of various size and scope are still being developed and refined at all levels within the DoD. As organizations have attempted to develop system architectures that are aligned with policies, significant obstacles have been encountered in implementing the guidance using the DoDAF construct.

The paragraphs below discuss some of the shortcomings that have been experienced with the implementation of systems architecture within the DoD and offer useful perspective when investigating aligning architecture with development.

2.1.1 Applicability of DoDAF Across the Spectrum of DoD Acquisition

The identification of the role or purpose system architecture should play within a given effort needs proper definition. As Maier states in his evaluation of DoDAF to

ANSI/IEEE 1471[1] conformance, organizations ultimately using the framework may have different objectives for architecture than the audience that it was originally developed to assist.

> *Although developed for acquisition supervisors concerned with interoperability, the DoDAF in practice is primarily used to produce architecture descriptions during the early-stages of system development.* (3 p. 19)

This observation illustrates that DoDAF is not a "one size fits all" tool. Organizations that implement DoDAF need to tailor their implementation to ensure that it provides useful information to support decision making. This criticism is also validated throughout Volume I of version 2.0 (1) where extensive time is spent discussing the need for architectures to be tailored to user's needs.

2.1.2 Alignment with Existing Systems Engineering Processes

At a US Army sponsored workshop entitled *Exploring Enterprise, System of Systems, System, and Software Architectures* in March 2009, the observation that was offered during the System of Systems working group accurately summarizes the poor alignment with architectures and the systems engineering process that are occurring.

> *Members observed that there are a lot of issues with respect to the use of the DoDAF for architecture development in any genre. The good news is that architecture work is being done. In many cases (but certainly not in all), programs are performing architecture tasks as part of their normal systems engineering efforts, but they are not using the DoDAF for architecture development. Rather, it seems a common practice is to develop DoDAF views to meet DoD requirements after the initial architecture work has been largely completed. Instead of an architecture development tool, the DODAF often is used as an "after-the-fact" documentation tool.* (4 p. 31)

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[1] ANSI/IEEE 1471-2000, *Recommended Practice for Architecture Description of Software-Intensive Systems.*

This statement highlights the need to align the architecture and the systems engineering efforts and re-enforces the inadequacy of previous versions of the DoDAF construct in facilitating that effort.

2.1.3 Lack of Processes for Maturing Architectures

Research that has examined the usability of the DoDAF framework cites the lack of guidance in how to mature DoDAF products as a central reason for why the architecture is not currently aligned with decision-making processes for a system.

> *Most fundamentally, weaknesses in the DoDAF have been identified as it undergoes transition from a static, descriptive tool to a tool that attempts to characterize dynamic system properties. Little guidance is provided on how to translate requirements into the design of the work products. As promulgated, the DoDAF does not have a companion architecture development process to take advantage of its interconnected views. As a result, many developers of DoDAF have treated it as a contract deliverable as opposed to a central communications tool in the design process."* (5 p. 14)

These issues highlight some of the obstacles that systems developers are currently encountering in application system architecting effort. These are major factors that are inhibiting a more holistic use of the DoDAF framework during system design and development. If statements that have been cited are examined in the context of each other, an interesting conclusion may be drawn. These issues may be related to the first criticism this research has postulated. In other words, because the architecting process "as implemented" historically is not necessarily well-suited for many areas (i.e. development), it has not been embraced and aligned with the standard practices. Because this has largely not occurred, effort and processes have not been adopted to mature these models effectively. Given this thought process, relevance and utility become important factors consider when discussing how the architecting process should be tailored.

2.2 DoDAF Version 2.0

The developers of DoDAF have recognized the aforementioned shortcomings as well as many others and attempted to address many of these concerns in Version 2.0 that has been recently released. Version 2.0 places a larger emphasis on the data contained within the architecture or models as opposed to the specific products to display the data which were the focus of previous generations of the framework. The following paragraphs discuss and summarize and key differences found in DoDAF V2.0 Volume I. The most profound change is a migration to a "data-centric approach" as described in Volume I. In plain terms what the developers of this model are trying to convey is that there is more emphasis on collection and storage and use of data needed for efficient and effective decisions and less emphasis on the development of specific architecture products. Ultimately, the developers are more concerned that the data is accessible to support decisions, and less concerned with the method of presentation due to various requirements of different stakeholders, which is a significant change.

The revised guidance also further highlights the distinction between the types of architectures. It begins by introducing the Enterprise and Solution architecture definitions and making a distinction between their uses within the DoD. Per Vol. I the definitions of each type of architecture are as follows:

> <u>*Enterprise Architectures:*</u> *A strategic information asset base, which defines the mission, the information necessary to perform the mission, the technologies necessary to perform the mission, and the transitional processes for implementing new technologies in response to changing mission needs. EA includes a baseline architecture, a target architecture, and a sequencing plan.* (1 p. 6)

<u>Solution Architectures:</u> A framework or structure that portrays the relationships among all the elements of something that answers a problem. This architecture type is not a part of the DoD Enterprise Architecture, but is used to define a particular project to create, update, revise, or delete established activities in the Department. Solution architecture may be developed to update or extend one or more of the other architecture types. A Solution Architecture is the most common type of architecture developed in the Department. Solution architectures include, but are not limited to, those SOA-based architectures developed in support of specific data and other services solutions. (1 p. 6)

Another major change in version 2.0 is a significant revision of the viewpoints for model. The three viewpoints used in previous version (e.g., Operational, Technical, and System) have been extended and significantly re-organized. The objective was to create more specific viewpoints that relate to the collection of architecture-related data which can be organized as useful information for the manager in decision-making. The revised viewpoints for DoDAF 2.0 and a brief definition are shown in Figure 1.

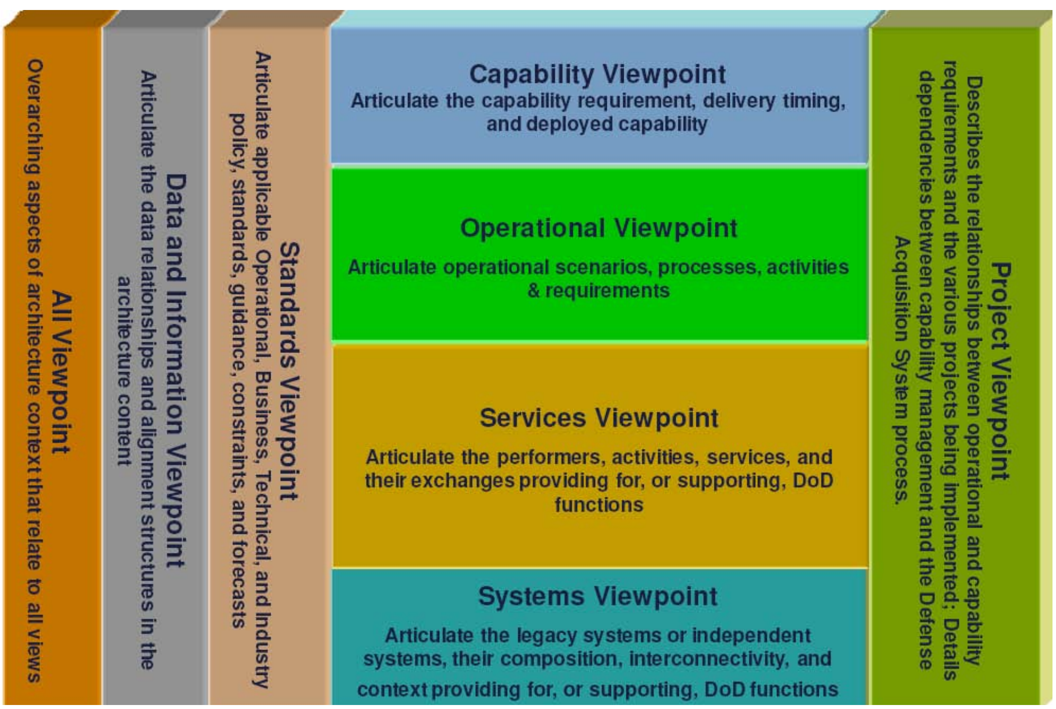

Figure 1: Architecture Viewpoints in DoDAF V2.0 (1 p. 21)

As can be seen in Figure 1, the views and their roles have been altered significantly. In addition to providing viewpoint definitions, Figure 1 illustrates the relationships of the views in the context of each other. The horizontally depicted views this chart show how the version 2.0 views relate to each other in terms of abstraction, migrating from capability oriented models downward to viewpoints of the underlying systems that enable them. The vertically aligned viewpoints show the vantages that transcend the various levels of abstraction and illustrate the rules, relationships and standards that govern them. The additional viewpoints were added in an attempt to provide more flexibility in the DoDAF model. The rationale for change is that with more specific viewpoints, organizations now have more freedom to create architectures that are aligned correctly to support the purposes that decision makers have defined for them.

This one of the reasons that the revised DoDAF guidance does not prescribe any mandatory model set for an architecture.   Instead, it chooses to concentrate on the data primary element for the architecture and allows the architect and stakeholders select the proper models and views that will help them in accomplishing the goals that have been identified for the architecture.

The notion of "tailoring" the architecture highlights another important change in the DoDAF guidance. In previous versions, the products within the architecture were rigidly defined. DoDAF 2.0 has recognized this as a shortcoming with the previous version and adopted a philosophy where the models and views need to be selected to support the goals of architecture. If models don't exist to support a given purpose well,

“fit for purpose” or composite views can be developed to help address the stated need and enhance the ability of the architecture to be purpose driven.

Finally, DoDAF 2.0 has offered new processes to help support the development of architectures based on the revised principles. This process is data driven and forces the community using the architecture to identify role, purpose and scope for the architecture initially. Then based on these inputs, the process identifies the data required to support those goals. After that has been completed, then questions of how to store, use and depict the data are addressed and agreed to by both the architect and the stakeholder. Once this is completed, the products are put into use and validated through feedback from the stakeholders. This process is enumerated in the DoDAF “six step process” which will be discussed and applied in later sections[2].

The remainder of this research will focus on implementing the revised architecting principles and processes outlined in the DODAF 2.0 guidance with the goal of proposing a solution architecture reference model that will address the needs of the space S&T development community. The following section details how the DODAF V 2.0 six step evaluation processes were used to structure the development of a system architecture that was tailored for the unique needs of a space S&T development environment.

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[2] For a complete description of the DoDAF 2.0 Framework, and its revisions Volume I & II should be consulted.

III. Methodology

3.1 Introduction

In Volume I of DoDAF 2.0, a six step process (Figure 2) is identified to assist the development of architecture. In this process the first four steps are focused on the development effort, and the fifth and sixth steps are focused on application and verification. This section will be structured to demonstrate how this process was applied to the architecting effort that was conducted. It will also include discussion regarding the effectiveness of the data gathering methods that were applied.

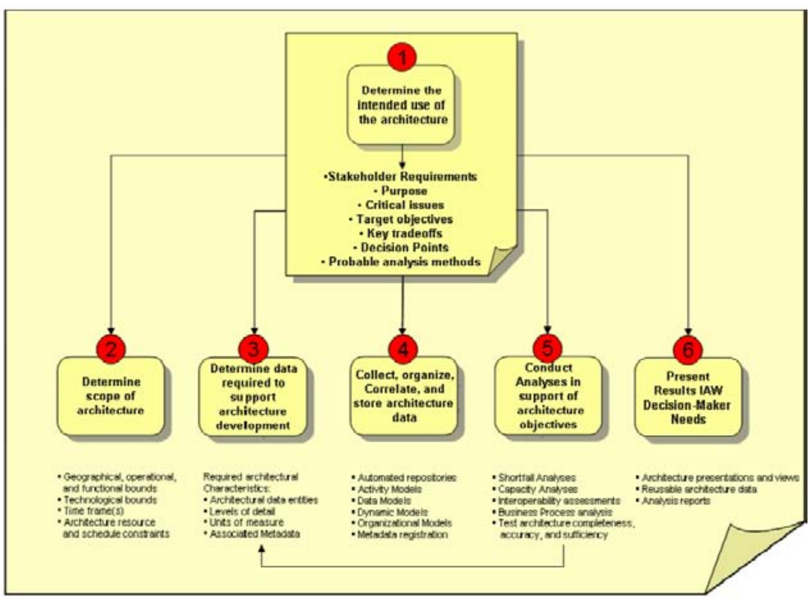

Figure 2 DoDAF Six Step development Process (1 p. 51)

3.2 Decision Focused Fit For Purpose Architecture

In DoDAF V2.0 Volume I, the first step of the development process is to determine the intended use of the architecture. The first step is described as the process for determining what the purpose of the architecture will be and determining the

objectives, identify critical data and success criteria for the measurement of the architecture. This step is typically driven by the process owner(s) and a common understanding is critical.

Initially, the identification of a process owner was an open question. Within the AFSPC[3] technology development community, adherence to DoD (CJSC62-12E) and AFSPCI (AFSPCI 10-103) policy regarding system architecting is not required. Due to this lack of higher headquarters reporting requirements, it was decided that the appropriate owners would be the program executives and/or milestone decision authorities for the space segment. The measures of success for a given architecture would be related to the architectures ability to help effect the outcome of the design under development in terms of completeness, timeliness and ability to identify and solve issues within the development process. It is important to note that none of these measures is quantitative. To evaluate the impact of the architecture properly, an individual would have to have relevant experience of an S&T development in order to properly assess the architecture's ability to aid a development.

To develop a cross functional understanding of how this architecture could be developed, a number of different stakeholders were surveyed[4]. The survey population was cross functional group of space system developers. Figure 3 illustrates the various

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[3] Note: This statement does not refer to AFRL SE practices. Although there are many collaborative efforts between AFSPC and ARFL in the space enterprise, they adhere to different guidance regarding SE practices. Reference appendix A for a more descriptive explanation of the various agencies who participate in the S&T effort

[4] See Appendix C – Subject Matter Expert Survey Form

discipline of the sample population and enumerates the number of individuals that were surveyed.

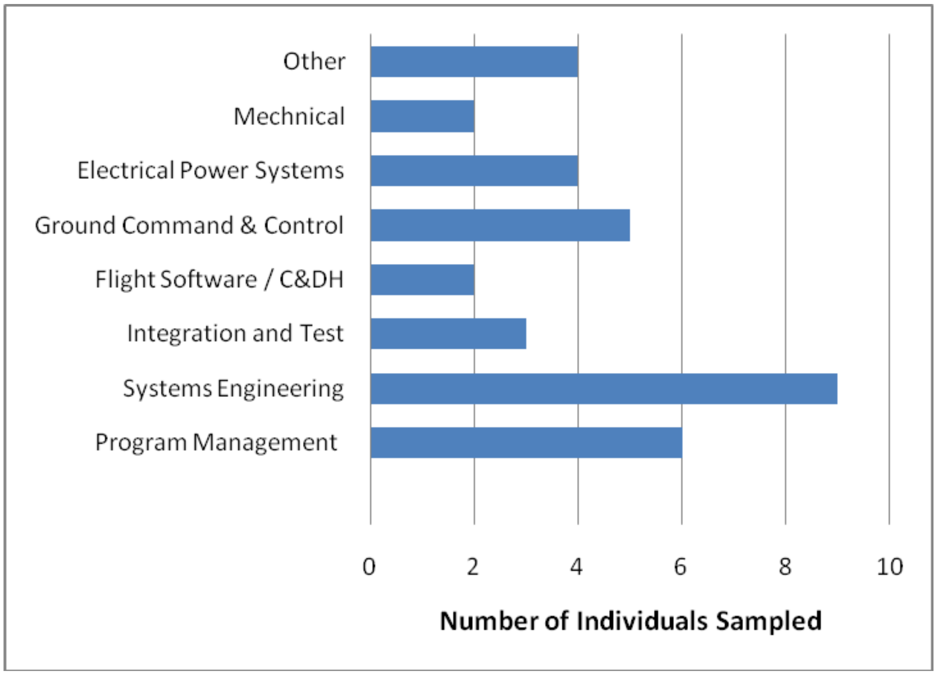


Figure 3 Subject Matter Expert Population Distribution

The goal in selection of the sample population was to gather a broad set of different expertise involved in spacecraft system development in order to have diverse perspective of how architecture could be applied across the various efforts.

The survey attempted to identify the goals of system architecting and translate the first few steps of the DoDAF process into easily digestible questions that could be answered regardless of system architecting expertise. The feedback from the initial survey was largely fruitless. Many of the responses were vague and people had difficulty providing concrete examples of the issues highlighted in the survey even when they were engaged in a discussion. As a result, the approach for data gathering was altered.

Process diagrams were developed for the various phases of the development to help provide context and frame the discussion. Rather than providing another series of surveys, interviews were conducted where the process diagrams were used as visual aids and the questions in the survey were approached throughout the conversation. At this point the same population was approached again. This activity resulted in more useful and diverse inputs regarding the purpose, scope, data and model applications for space S&T architecture.

After interviews were completed, information from the discussion was captured in a spreadsheet identifying the role of the individual, lessons or suggestions where architecture could help support development, the data that would be relevant and notions of how it may be represented using either a heritage DoDAF view or a product/ document that is commonly used within a spacecraft development.

Using the data obtained, the information was then synthesized to determine what models and data may be a relevant part of a space S&T architecture. As ideas for views and data began to emerge, they were added into a table which would ultimately become the DoDAF reference model for space S&T. An excerpt of the model is shown in

Table 1 below.

Table 1 Space System Architecture Model Extraction

	Mission Phase	Relevant Architecture Information	Purpose/ Function	Maturity	Product(s)	DODAF Model Reference
	Pre - system Acquisition					
		Critical System Requirments Capabilties / Contraints / Outcomes	- Identify required program outcomes / measures of effectiveness - How residual capability may be used if deemed sucessful - Communicate aspects of the mission that must be adhered to and cannot be traded within the project	Draft	Mission Plan	AV-1
		Organizational Roles	- Establish lines of authority - Delegate project roles and responsibilities		Mission Plan	OV-1 OV-4
		Schedule	- Program Driving Schedule Requirements - Key schedule driven technical decisions		Intgrated Milestone Schedule	PV-2

The table that became the reference model[5] was constructed to show each phase of the design process and briefly highlight the purpose for the model or tool for the given timeframe. It was originally intended only be to be a visual aid and organizational tool while models were being collected and developed. However, as the effort progressed it became clear that this could be a very useful "dashboard" for the architecture helping people to quickly understand the information contained within, thus making it more accessible. The reference model immediately helps the user understand the purpose of the various views, as well as the how a view's role may have changed based on the mission phase. Model maturity for the phase is also highlighted to give the user an understanding of the quality and completeness of the underlying data and its susceptibility to change.

[5] Note the complete reference model is shown in Appendix D. Additionally, each one of the views and the rationale for inclusion in the reference model is included in chapter 4.

Finally, the reference model identifies the applicable documents, models or tools where the information resides. The reference model also highlights the applicable DoDAF view names to help the user easily understand the association between the document and the DODAF view. Specific explanation of each of the column headings within the reference model are provided in Table 2.

Table 2 Framework Heading Information

Mission Phase	Identifies the applicable mission phase for the architecture models
Relevant Architecture Information	Identifies information within the view that would be useful to the stakeholder
Purpose/ Function	Brief statements describing the information within the model and potential relevance to the design under development
Maturity	Lists document maturity at a given phase in the development: *-Initial: document released by responsible party, document should not be considered vetted and any decisions based on documentation should be validated with the author for accuracy* *- Final: document has been reviewed and revisions have been coordinated, reader should assume information to be accurate and complete* *- Living: document regularly updated and posted, periodicity of updates should be understood, questions regarding the currency of the document should be coordinated with owner*
Product(s)	Identifies the program document that contains the relevant architecture information
DODAF Model Reference	Documents DODAF reference model number
Notes:	Any other relevant information that is required

The goal of this reference model ultimately became to provide a summary of the architecture and its maturity in the context of the system development. Ideally, this model would be the first place that an individual could explore to help understand where to go in order to look for applicable data and gain some understanding with respect to the quality/maturity of the information. Additionally, depending on what tools were used to implement the architecture, it may be used to direct a user to the information source.

After the reference model was completed, a limited review of the information was conducted with select individuals from the original sample population who were initially interviewed to verify applicability of the models to the lessons that were identified. This effort proved to be helpful identifying some additional potential models and applications. Due to time constraints a complete validation effort with stakeholders was not conducted. Additionally, this architecture framework was not taken and adopted for a space S&T system under development. Although models, meta-data and in some cases data types were identified, the process of developing a construct gather and apply them in an architecture was not completed. This exercise would be an excellent follow on activity for additional research and would provide useful insight regarding both the level of effort required and the effects of the architecture on the system.

3.3 Summary

Table 3 lists the architecture development steps from DoDAF 2.0 and summarizes the activities that were conducted in support of developing the architecture, as well as uncompleted work that could be performed to refine this concept. The table highlights the

activities that were performed; all discussion of the results is included within chapter four.

Table 3 Space System Architecture Development Summary

DODAF Development Step	Activities Performed
1. Determine the intended use of the architecture	Surveys and interviews were conducted to highlight problems typically encountered with space S&T acquisitions and identify roles an architecture could play in resolving them
2. Determine the scope of the architecture	The various elements of the S&T space system were examined and boundaries were drawn based on stakeholder inputs
3. Determine data required to Support the architecture development	- Collected specific lessons regarding problems previously encountered with space S&T developments - Synthesized lessons by examining each lesson in the context of "applicability to system architecture" – what products or processes address the problem discussed in the lesson. Is this relevant to system architecture and how?
4. Collect, organize, correlate and store architecture data	- Developed a model framework that identifies relevant architecture data, identifies purpose(s) for the model and discusses maturity through the design life cycle - Although candidate models or formats were identified the architecture was not implemented, as a result no data was collected or correlated in a tool
5. Conduct analyses in support of architecture objectives	Not executed because candidate architecture was not implemented
6. Present results IAW decision makers needs	Not executed because candidate architecture was not implemented

The application of the DoDAF process for architecture development was a useful effort. It provided valuable insight into the challenges that architects encounter in the application of architecture and underscored the need for processes or methods to mature the architecture during its development. Specific lessons and insights will be discussed in more detail in the following chapters which review the outcomes of this effort and discuss in detail the proposed architecture that was developed.

IV. Analysis and Results

4.1 Initial SME Feedback on System Architecture Use

One of the primary intentions for this effort was to identify how system architecture could be used in an effective fashion for a space system development in the science and technology development arenas. DoDAF version 2.0 places a renewed emphasis on stakeholders identifying the role and purpose architecture should play within a system or enterprise. This is supported by broader DoD systems engineering reviews and recommendations which challenge users to tailor the content and rigor of the SE effort to align with their needs.

In order to develop specific ways a tailored architecture could support a development, the larger question of purpose and roles for architecture in this environment needed to be addressed first. As this question was posed to various individuals, certain themes emerged from the responses. Most individuals identified the use of system architecture as a tool to preserve information for the future. A much smaller subset identified the possibility of using system architecture as a construct for gathering, storing and maturing information to assist a spacecraft development. A summary set of objectives for a space S&T architecture that was decided upon based on the responses is shown below.

- Preserving Critical System Development Information: S&T missions must ensure that the “as-built” system information, issues encountered and lessons learned are preserved to help enable subsequent efforts that are derived from the concepts that are demonstrated
- A communication tool to coordinate and integrate critical programmatic and technical information among the various system stakeholders throughout the development process

- A construct for identifying how information from various program elements should be matured over time to result in a system that meets its mission objectives

As the conversations continued and a common understanding of topic was reached, the development of boundaries for a space system architecture evolved quickly. All individuals surveyed responded that boundaries should follow functional lines. However, they also expressed there was significant information about other systems that needed to be preserved to have the appropriate amount of context. The Venn diagram (Figure 4) illustrates the boundary that was ultimately developed for the architecture example illustrated in this work as a part of step two in the DoDAF six step process. Although this architecture was focused on the spacecraft element of a S&T space system, the other components of the system cannot be ignored. This is especially important in the early stages of design where mission requirements are developed and functional responsibilities are allocated to various component areas. Figure 4 also helps to highlight relationships among the various systems and illustrates some of the information themes or "meta data" from other systems which must be preserved within the space segment architecture that relates to the other system elements.

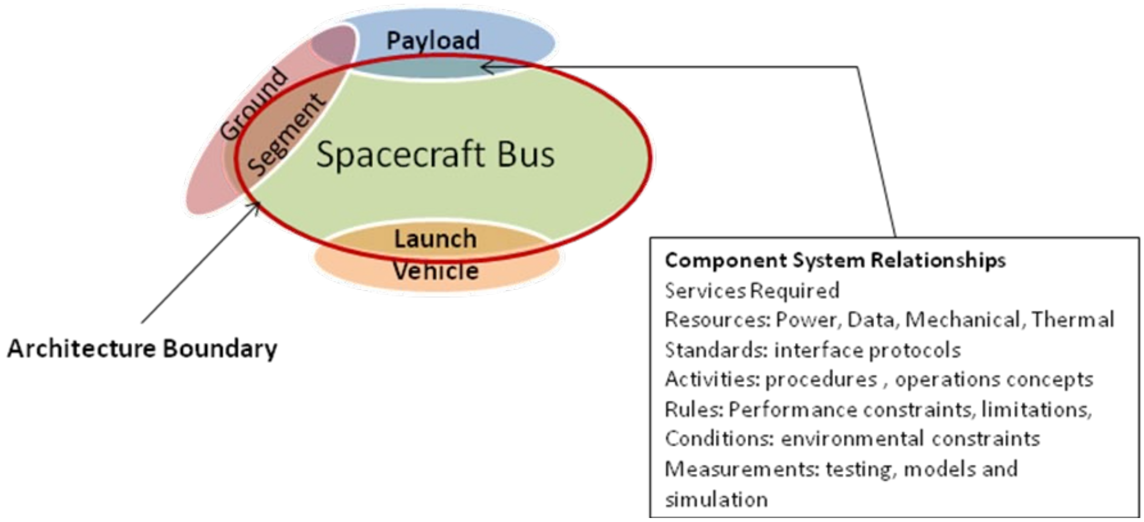


Figure 4 System Architecture Boundary Diagram

Review of the boundary that was drawn after the fact resulted in an interesting question regarding the boundary of the architecture that was developed: At what level of abstraction is it most effective to develop an architecture for a given space mission? If a mission decision authority wanted to use this tool to manage the development across all system elements, the proposed architecture would need to be extended further. This topic is discussed in further detail within the conclusions.

4.2 Application of the SME Feedback into Principles of the Architecture

One of the key insights from system developers was the need to synergize any architecture models with the work that was being conducted in support of the design to enhance the ability of architecture to keep pace with the maturation of the development. As a result, the goals associated with this implementation of system architecture were to use products that are commonly created throughout the system acquisition process and

make them more effective by highlighting their role in the development with the use of the framework. Throughout the process of cross-referencing program documentation with DoDAF model descriptions, several cases showed existing documentation could satisfy more than one view within the DoDAF construct. This is because in order to achieve the intended purpose of the document as they currently exist, they typically leverage information from several models.

It is important to note that if architecture models are going to be developed and maintained within the document special attention needs to be paid during the document development process to ensure that expectations for the model are still satisfied. If a given product is going to include or be labeled as a "DoDAF model", the requirements for what data should be contained within the model still must be adhered to. The goal of this approach is not intended to re-define existing models. It is meant to offer streamlined methods for model development and maintenance of relevant views. This can be accomplished by ensuring the various DoDAF model data definitions and requirements in Volume II are referenced and checked during the document development and editing.

Additionally, in cases where certain models are contained within a given document or tool it is also important to ensure that the information is easily identifiable and extractable. This may be accomplished by possibly by having detailed citations or annexes that allow the user to navigate to the documentation or providing specific references to location in the framework.

Throughout the development of architecture reference model significant attention was also paid to what information was required to achieve the purpose outlined above.

As a result, several “Fit For Purpose or FFP” views were envisioned to help identify program and system information that DoDAF construct did not expressly identify. This tailoring process is strongly encouraged by the new guidance set for forth in version 2.0 to help increase the relevance of the architecture to the stakeholders based on their input. Example information for the various models that have been proposed within the architecture framework are included in Appendix B. Information contained within this appendix is not meant to imply syntax for the model or a method for it to be accomplished. Instead it is offered as an aid to provoke discussion of what information is relevant for the mission at hand.

Using the insights described above, the concepts for a tailored system architecture reference model was developed attempting to demonstrate how these goals could be accomplished. The following sub-sections chronologically step through the development process and discuss how a tailored system architecture may assist the invested parties in achieving the desired outcomes for the mission, while preserving essential information for the development of follow-on operations or technology development.

4.3 Tailored Space Architecture for S&T System Development

The following sub-sections will each discuss a phase of the S&T design process (pre-system acquisition, concept refinement, preliminary design and critical design). Each phase will be introduced and accompanied by a process diagram highlighting major activities occurring within that time frame will be depicted to provide adequate contextual information to the reader. Then the reference model for the phase will be presented. The model will identify the various recommended program products to be

used within the given phase and their relationship to the DoDAF models. It also highlights important attributes of the models at a given point in the development. In every subsection where a new product is introduced, summary information is provided regarding the product and its intended use. Additionally, a narrative or relevant lesson is included below the summary that helps validate the practical purpose of the products. If a product update is required in subsequent mission phases a discussion of the how it's role has been altered is discussed.

4.3.1 Pre-Systems Acquisition:

At the onset of an S&T mission, many decisions need to be made quite early in the program that have will have a profound outcome on the acquisition. In this phase decisions are made quickly and may be communicated in an "ad hoc" fashion which does not allow parties who subsequently join the development to appreciate the impetus. This underscores the criticality for program tools that help develop understanding regarding the system, its associated risks, and technical challenges. As can be seen in Figure 4, after the decision to accept a mission is made, system development processes immediately follow. If these decisions and processes are not well defined and documented they will delay subsequent requirements analysis and development activities.

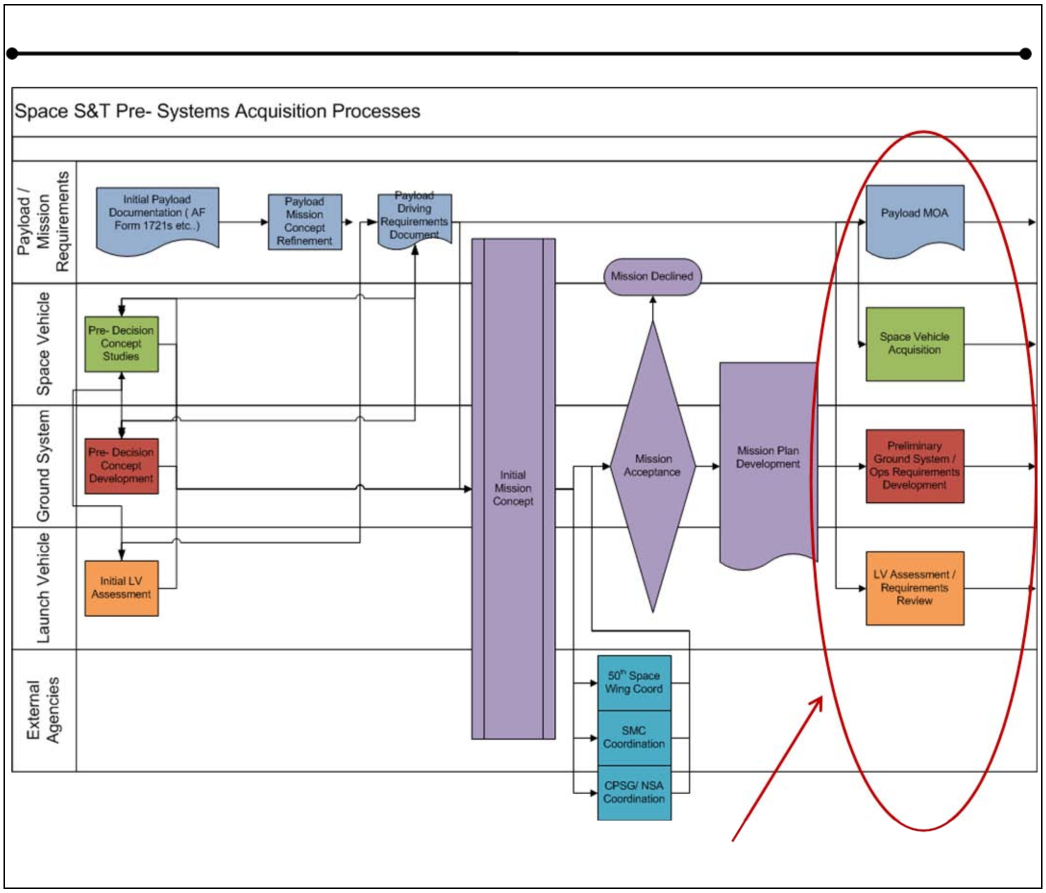


Figure 5 Pre-Systems Acquisition Process Diagram

During pre-systems acquisition, several areas were identified where system architecture models and processes could help mature expectations for different elements of the program appropriately before a "mission acceptance" decision is made. Table 4 lists relevant architecture information identified throughout this research and highlights rationale for the product and maturity. The following section examines the purpose for the various products and attempts to illustrate how their presence could provide valuable technical and programmatic insight to support decision making.

Table 4 Preliminary Design System Architecture Information

Mission Phase	*Relevant Architecture Information*	*Purpose/ Function*	*Maturity*	*Product(s)*	*DODAF Model Reference*
Pre - system Acquisition					
	Integrated Risk List	**- Cross functional list of risks compiled across integrated product team**	Living Document	Consolidated Risk List	FFP-1A
	Integrated Risk Plan	**- Documentation outlining the program's risk posture and threshold's for reporting and mitigating risk**	Initial Delivery	Consolidated Risk Plan	FFP-1B
	Schedule	**- Program Driving Schedule Requirements - Key schedule driven technical decisions - Giver /receiver relationships that span different program elements**	Living Document	Integrated Milestone Schedule	PV-2
	Critical System Requirements Capabilities / Constraints / Outcomes	**- Identify required program outcomes / measures of effectiveness - How residual capability may be used if deemed successful - Communicate aspects of the mission that must be adhered to and cannot be traded within the project**	Initial Delivery	Mission Plan	AV-1
	Organizational Roles / Boundaries	**- Establish lines of authority - Highlight system boundaries that will require interface control documentation to be developed - Delegate project roles and responsibilities**	Initial Delivery	Mission Plan	OV-1 OV-4
	Design Standards and Life Requirements	**- List of regulatory standards that program is required to comply with - Understanding of nominal SC design life and risk classification (i.e. Class A, B, C...) - List of any international treaties that may affect program decisions - List of applicable technical standards**	Initial Delivery	Mission Plan	STDV-1
	Critical Program Documentation	**- Identify required documentation/ information /models from various system developers - Highlights the how many iterations are planned throughout the document lifecycle - Identifies delivery dates for all information among stakeholders**	Living Document	Program Documentation Maturity Matrix	FFP-2
	Open System Trades	**- Description organized by subsystem of open design trades and decisions that need to be completed - Each trade should have an owner and associated due dates that are aligned with program constraints**	Living Document	Trade / Decision tracking matrix	FFP-5

<u>Consolidated Risk List (FFP-1A) and Plan (FFP-1B):</u>

The risk plan outlines the strategy for risk management, scoring and defines a risk posture for the program. The list provides an integrated view of all the risks within the system in order to effectively identify, manage and mitigate risks effectively.

Many S&T missions are willing accept more program risks due to the finite nature of the mission. For example many S&T missions accept single string designs which immediately set a certain risk posture for the program. By defining major program risks early it helps to set a frame of reference for acceptable risk within the

program throughout the program and makes it easier to understand what level of risks must be mitigated during the design phase or conversely can be accepted.

Integrated Milestone Schedule (PV-2):

Prior to making the decision to embark on a mission, it is critical to define the elements of a program that are understood to challenge or constrain the trade space in terms of schedule. An organized understanding of what activities represent the highest schedule risk for the development needs to be compiled at the earliest stages of the program in order to develop a feasible project timeline.

Some components in common small satellite designs routinely drive the ability to begin system integration. The procurement of a SGLS transponder is a perfect example. Acquisition time for a transponder is typically on the order of 16 months. This is due to the fact that specific crystal must be grown for oscillators which create a wave form that corresponds to an approved radio frequency. This process takes several months. Additionally, the approval for a specific frequency is also a lengthy process which will drive schedule risk. Therefore, in order to achieve total system development timelines of 24- 36 months, critical decisions regarding parts procurement will have to occur in advance of design reviews and approvals in many cases to mitigate schedule risk.

Mission Plan (AV-1, OV-1, OV-4, STDV-1):

During the pre-acquisition phase, a Mission Plan is an umbrella document that summarizes the approach for the mission, the organizations that will be involved and the outcomes that are desired. This document can take various forms and contain differing information depending on the developing organization. While polling individuals

regarding this mission phase the areas discussed below were highlighted as items that needed to be documented at the onset of a mission.

Capabilities, Outcomes & Measures of Effectiveness: S&T missions do not uniformly have a process for measuring the success of a technology on-orbit. The mission plan must identify how success will be managed to ensure that it appropriately flows into the design. In many cases mission requirements, such as higher than planned payload duty cycles and 100% data collection at the ground, emerge in later phases. If these are not appropriately defined before mission segment requirements documentation is formulated, then the appropriate capability may not exist.

Design Standards: Common problems encountered within S&T developments include how c standards should be applied to achieve the desired outcomes. In many cases the programmatic effects are not appropriately considered when a decision of how to apply a standard is made. For example, decisions regarding piece part procurement standards can drive component piece part procurement cost by as much as six times if parts screening is required to meet standard (6 p. 11). Additionally, the required standards can have significant effects on lead time for procurement based on availability and requirements. These decisions of how to apply standards needs to be closely evaluated and framed with desired mission outcomes and risks tolerances for a project to strike a successful balance. This activity needs to be done prior to mission acceptance to avoid costly mis-conceptions and delays during the requirements decomposition and design phases. This point is re-enforced by the fact that many decisions regarding applicable standards may be a result of prior precedent and may or may not be appropriate for the outcomes that are desired for the mission currently under

development. If programs don't critically examine the required standards for each mission, they may unnecessarily levy over restrictive requirements such as cleanliness that will end up wasting time and money adhering to standards that may not be required.

Design Life: In many cases expectations for mission life are not clearly defined or adhered to for S&T missions. Perceptions that following a demonstration residual capability may exist that can be used operationally sometimes jade quality expectations. Developers need to clearly state what type of system is desired and not force artificial expectations for design robustness that exceed the actual need.

Waiver Authority: It is equally as important to define processes for requesting waivers to the approved standards understanding the regulatory processes that surround them and identifying waiver authorities for the applicable standard if they can in fact be waived. In many cases waiver authorities do not reside within the program office (i.e Form 813 Environmental Assessments). Additionally, some regulations per organizational policy are unable to be waived so compliance must be achieved in the mission design.

Program Documentation Maturity Matrix (FFP-2):

A common understanding of what program documentation will be delivered and how it matures is common request when discussing development lessons learned. As different program elements interface with each other the ability to understand what documents will be delivered and how they will mature through the course of the development is a proactive way to enhance dialogue surrounding interfaces and on what time tables design trades must occur. This matrix can also be used to re-enforce

expectations with respect to information contained within the document and develop a common understanding among invested parties.

In many cases expectations for documentation vary significantly, and costly time can be spent be spent in review and revision because a document did not meet its intended purpose. The use of this view can help baseline expectations and set the focus for the initial document. This view is not intended to replace detailed requirements for a document. However, drastically different ways of documenting system information exist across the space enterprise. This view can help an individual understand where information resides, as well as how it will mature through the course of a development. This product should have the widest distribution throughout the program so all invested parties understand the plan for documentation evolution.

Trade / Decision Tracking Matrix (FFP-5):

From the onset of concept development across the various system areas, trades emerge as the vision for the mission is constructed. These trades will have widely different time horizons for decision making. As trades are encountered it is important within a development to ensure that all open trades are accounted for and the deadlines for trade decisions are well understood. This can help avoid hasty time based decision making that is not well coordinated or documented. In many cases subsystem engineers do not fully consider the ramifications of how design changes within their system will affect other systems. Views and processes that help reinforce this process will help mitigate issues during system integration and testing. A second benefit of this view is program decision authority insight. This view will help in ensuring that consensus has

been reached by all required parties and provides useful insight leading to major program reviews and decisions regarding the amount of outstanding work.

An example of how this product can be useful throughout the design phase of the acquisition occurred during the development of a flight software development for a flight software system. In this case the flight software engineering team made the decision to not implement the concurrent ability to range and receive telemetry at the same time without consulting the larger systems engineering, ground operations and telecom engineering team. This implementation has serious implications for operations team, especially in an early orbit anomalous situation post launch where the ability to see telemetry and range on the vehicle would be highly desirable A product which helps to track program trades and helps foster cooperative decision making is a useful asset for a system acquisition.

4.3.2 Concept Refinement

Concept refinement and requirements development is often a challenging phase of a system development. In a very short period of time, the program must adequately define system requirements and the developer is expected to understand, refine decompose, and allocate all of the requirements for a given system. Within the space S&T realm, this mission phase is expected to be completed within a very short period of time and is often done with high levels design uncertainty among system elements.

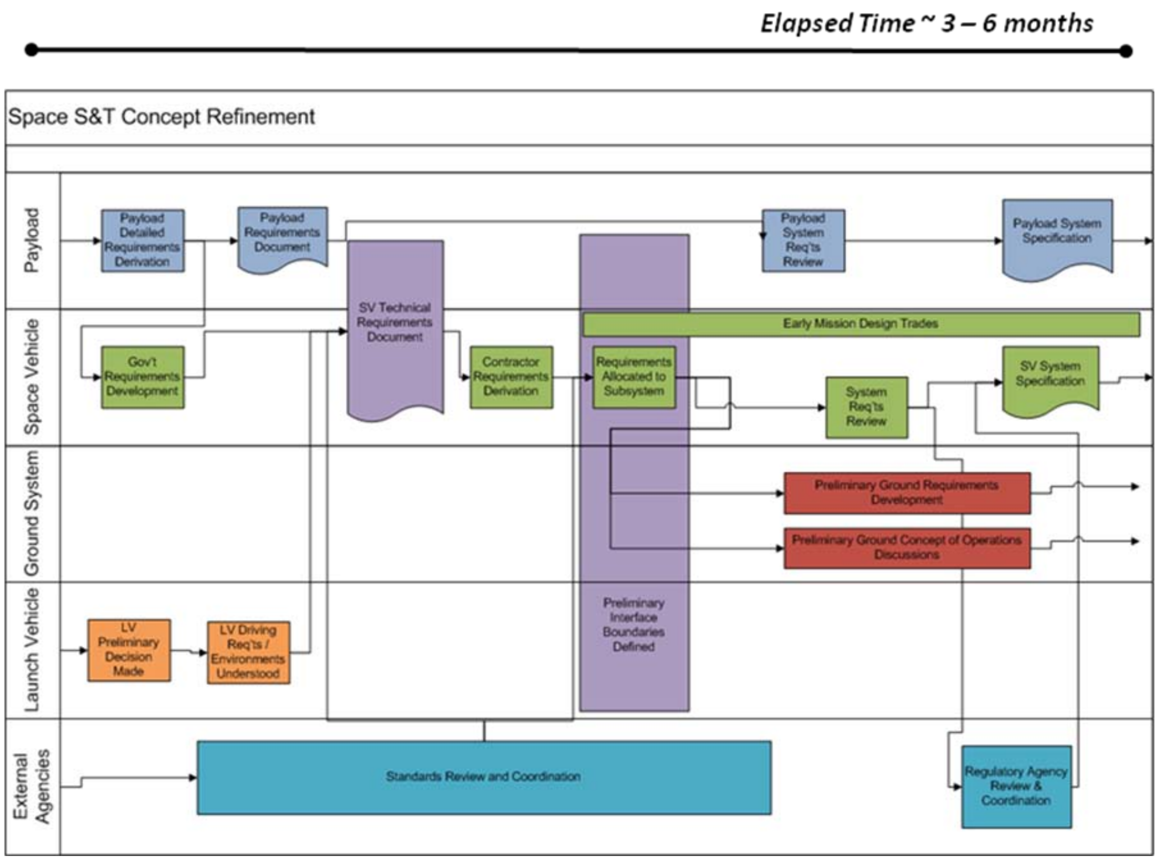


Figure 6 Concept Refinement Process Diagram

Sound requirements development and refinement are cornerstone's of a development's success. However, in many instances this phase of the mission has been plagued by poor documentation and systems engineering (6 pp. 27,31). This underscores the need for information that can help the system developer and/or the program decision authority with ways to effectively structure and document decisions throughout this phase.

There are two distinct efforts within this phase. The first involves the acquiring agency articulating what is required of the system under development. This effort should heavily leverage and refine many of the architecture views outlined in the previous phase in particular the Mission Plan. As can be seen in Table 5, effort early in this phase is geared towards ensuring that the mission needs, outcomes and standards are completely

articulated. This ultimately results in the delivery of a Space Vehicle Technical Requirements Document to the system developer.

Table 5 Concept Development Process Information

Mission Phase	*Relevant Architecture Information*	*Purpose/ Function*	*Maturity*	*Product(s)*	*DODAF Model Reference*
Concept Refinement					
	Integrated Risk List	- Cross functional list of risks compiled across integrated product team	Living Document	Consolidated Risk List	FFP-1A
	Schedule	- Program Driving Schedule Requirements - Key schedule driven technical decisions - Giver /receiver relationships that span different program elements	Living Document	Intgrated Milestone Schedule	PV-2
	Critical System Requirements Capabilities / Constraints / Outcomes	- Identify required program outcomes / measures of effectiveness - How residual capability may be used if deemed successful - Communicate aspects of the mission that must be adhered to and cannot be traded within the project	Final Delivery	Mission Plan	AV-1
	Organizational Roles / Boundaries	- Establish lines of authority - Highlight system boundaries that will require interface control documentation to be developed - Delegate project roles and responsibilities	Final Delivery	Mission Plan	OV-1 OV-4
	Required Standards, Design Life Requirements	- List of regulatory standards that program is required to comply with **- Includes Preliminary LV Environments and Loads** - Understanding of nominal SC design life and risk classification (i.e. Class A, B, C...) - List of any international treaties that may affect program decsions - List of applicable technical standards	Final Delivery	Mission Plan	STDV-1
	Requirements Functionally allocated and derived for each subsystem and component	**- System Developers repsonse to the Technical Requirements Document** **- Identifies how requirements will be allcoated among various systems** **- Highlights functional responsibility for each subsystem** **- Provides critical data regarding system boundaries and interfaces**	Final Delivery	SV Requirments Specification	FFP-4
	SV Technical Requirements Documentation	**- Complete list of performance requirements for the Space System** **- Delivered by the government to the contractor / agency responsible for space vehicle design, development and integration**	Initial Delivery	SV Technical Requirements Document	FFP-3
	Open System Trades	- Description organized by subsystem of open design trades and decisions that need to be completed - Each trade should have an owner and associated due dates that are aligned with program constraints	Living Document	Trade / Decision tracking matrix	FFP-5

A strong emphasis throughout the beginning of this phase should be to solicit feedback from external agencies. In many instances this coordination can allow for more current requirements or standards to be applied and included prior to delivery to the developer thus avoiding confusion and iteration later in the design review process. Once this information is coordinated, it should culminate in the delivery of a comprehensive technical requirements document being delivered to the developer in

order to convey system requirements in fashion that allow for the agency to fully evaluate the merits of a design.

Following the acceptance of a system requirements document the second phase begins. This is where the developer to begin the process of reviewing, refine, decomposing and allocating the requirements to the various subsystems. This is an effort intensive process because complex interfaces exist between various systems. For this reason, a common understanding of what constitutes a complete requirements baseline is a useful benchmark for both the system owner and the developer by creating a set of expectations to evaluate the completion of this phase.

Mission Plan (AV-1, OV-1, OV-4, STDV-1):

This update should be focused on clarifying any changes or omissions to the critical system requirements, outcomes and standards. The revision of this document should be well-circulated with external agencies to ensure that properly regulatory guidance and best practices are implemented. In many cases revisions to guidance and policy do not align well with acquisition timelines.

SV Technical Requirements Document (FFP-3):

Following the validation of critical outcomes and standards, the acquiring agency should release a comprehensive systems requirements document that elaborates on the desired outcomes for the system by detailing significant system and subsystem requirements. Some may suggest that this element is not required and it should be the responsibility of the developer to derive from the required capabilities and outcomes. However, in most cases the agency has expectations for design development and test. If the developer is expected to derive system or test requirements without the guidance that

a document comprehensive requirements document would provide, serious discrepancies in the approaches taken with respect to requirements and standards may be likely.

A good example of the need for detailed requirement documentation can be seen in the development practices of the DoD Space Test Program. The DoD Space Test Program will commonly take risks in an accepting a single string spacecraft design due to mass and volume constraints associated with their space lift opportunities. However, in order to mitigate that risk, rigorous test requirements which may not be typically required for an S&T such as full MIL-STD 1540-E are commonly levied to screen for workmanship issues and infant mortality. Without these detailed specifications being documented in a technical requirements document to the developer, it is unlikely that they would adopt the preferred approach. This would result in extra time and cost expended in order to come to a consensus.

Space Vehicle System Specification (FFP-4):

This view represents the complete set of requirements associated with the system and the methods that will be used to demonstrate this requirement. The requirements specification should demonstrate how requirements are organized at the system, sub-system and component levels. Recommendations for constructing this view are well documented in within the DISA Data Item Description (DID). This proposed formatting does allow tailoring and does not have specific requirements associated with how the document is prepared or managed. However, careful consideration should be paid to the approach that is taken.

Several interactive tools are available that allow the user and the developer to trace requirements compliance from the component to the system level. This capability

significantly enhances the ability to work with the information and assess changes as they are encountered throughout the design process. This is important in the S&T environment because it allows the individuals associated with design trades to more effectively understand the impacts of change throughout the development process in closer to real time. These lessons can be applied into final interface control documentation and used to assess overall suitability entering the review. If issues are encountered during these activities, mitigations should be developed prior to final design review to ensure that developers can successfully transition from design to integration at completion of the review. These steps will help all parties validate the design and give them the requisite data to make informed decisions when planning for later phases of the mission.

4.3.3 Preliminary System Design

The name for this phase can be somewhat of a misnomer. Even though the first iterations of the design process are under development, many elements need to be completely solidified at this point in the design process. Additionally, this tends to be the point in the project where detailed interface boundaries and specifications must be developed among sub-systems and systems.

As can be seen in the figure below, much of the effort expended throughout this phase is dedicated to resolving various design decisions and trades. Tools that assist both the program developer and procuring agency add structure and organization to this time are particularly important. Many of the systems architecture products that were

mentioned previously (i.e. schedule and CDRL list) within the chapter play a significant role in aiding this process.

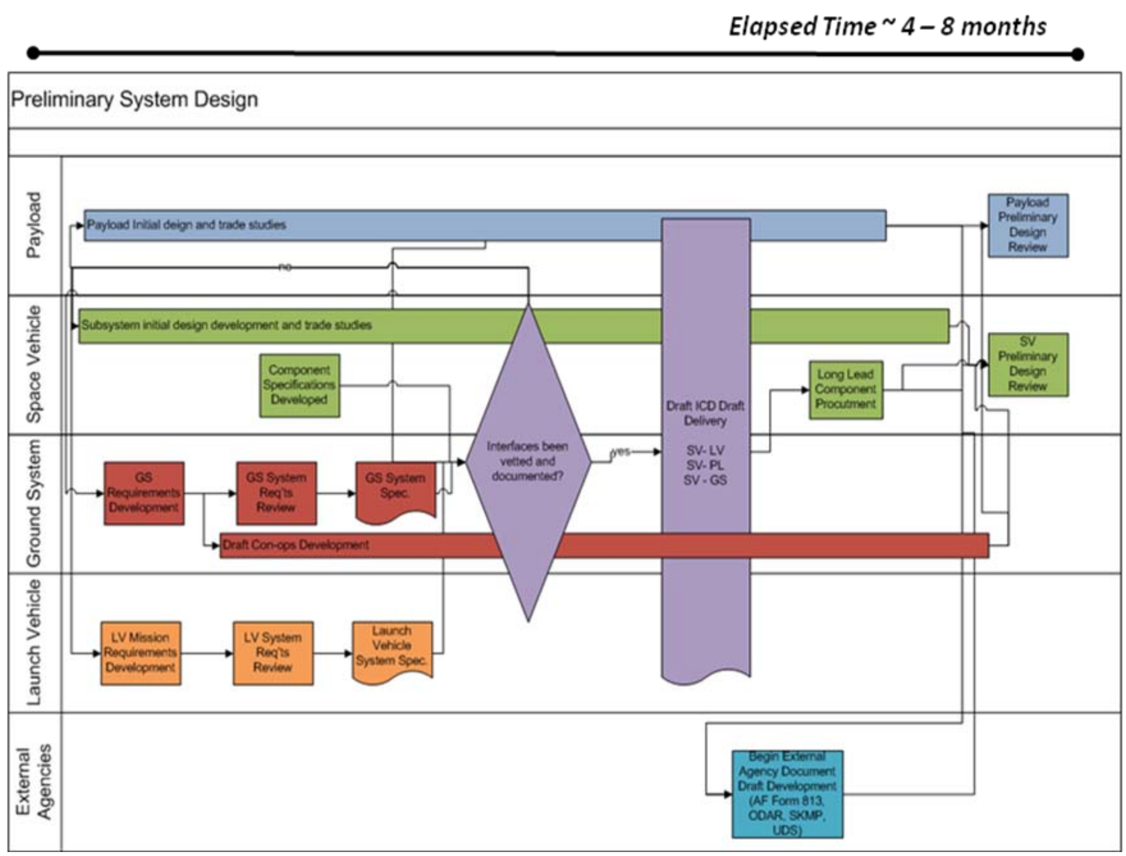


Figure 7 Preliminary System Design Process Diagram

The preliminary design phase is unique because although the preliminary design review marks the closure of the phase, some milestones that are of equal or greater importance must occur before this happens. As individual subsystem and system designs emerge and component trades for the various systems are under way, the schedule pressure of placing component orders before the any design review occurs in order to have a product by the close of the design phase is looming. This can be very difficult because usually the components that fall into this category are some of the most important system elements (avionics, flight computers and transceivers). The need order

components early also an additional challenge for the systems engineering team to ensure the requirements and interfaces for the component and the systems are properly vetted. Models that assist the program in fully describing and vetting the system interfaces and documenting them prior to hardware procurement decisions was the most widely recognized application of system architecture throughout this mission phase.

Table 6 Preliminary System Design Architecture Information

Mission Phase	*Relevant Architecture Information*	*Purpose/ Function*	*Maturity*	*Product(s)*	*DODAF Model Reference*
Preliminary System Design					
	Integrated Risk List	- Cross functional list of risks compiled across integrated product team	PDR Delivery	Consolidated Risk List	FFP-1A
	Operational Environment	**-Matrix documenting how test requirements that have been levied are satisfied with test (at both the component and system levels)** **- Identification of the method that will be used to verify the requirement** **- Identification of any potential non-conformances***	Initial Delivery	Environmental Test Verification Matrix	FFP-7
	System Interface Control Documentation	**- This will be a suite of documents, the mission plan should identify critical system boundaries that reuqire a formal interface control document** **- Minimum Criteria: SV - Ground and Payload to SV ICD initial drafts must be complete** **-Other pertinent ICDs: LV - Spacecraft, Component interface ICD**	Initial Delivery	Interface Control Documentation	SV-1 / SV-6
	Schedule	- Program Driving Schedule Requirements - Key schedule driven technical decisions - Giver /receiver relationships that span different program elements	Living Document	Intgrated Milestone Schedule	PV-2
	System / Sub-system Design Specifications	**- Partial Preliminary understanding of system/subsystem design** **- Allocation of required system functions to configuration items** **- Demonstration of how system requirements are satisfied by design**	Initial Delivery	PDR Design Presentation	SV-5
	Open System Trades	- Desription organized by susbsystem of open design trades and decsions that need to be completed - Each trade should have an owner and assocaited due dates that are aligned with program constriants	Living Document	Trade / Decision tracking matrix	FFP-5
	Technical Performance Measures	**- Demonstrate design peformance to critical program requirements outlined within the requirements document**	Initial Delivery	Technical performance budget	SV-7

Environmental Test Verification Matrix (FFP-7):

A critical element of component and system design is finalizing the environmental conditions that the space vehicle will experience throughout launch, upon separation and in space. This can be complicated in the S&T environment, because there are instances where acquisition begins without a complete understanding of what launch

vehicle environments will be experienced. Regardless, of whether or not the environmental conditions are known, a best effort needs to be made to indentify an enveloping environment for testing as early as possible. In many instances insufficient testing can put undue risk to testing at the space vehicle and drive cost later in the program. Also, incorrect assumptions regarding force limiting can lead to potential susceptibilities. The acquiring agency should strive to define environment at the launch vehicle interface before any requirements are flown for component level testing is initiated. Defining these environments will pay large dividends later in the program by avoiding very extensive and costly tests and analysis later in the program. If there is some level of uncertainty that cannot be resolved prior to component level procurement, the acquiring agency must either accept the risk or plan for significant cost growth later in the program. Documentation that details the tests environments for each component and the test methods used for verification will help in baselining expectations. A matrix that identifies verification methods is an effective method to help ensure that there is consensus for accomplishing this.

A previous satellite failure demonstrates an example of what can occur if environments aren't well understood. In this case, decisions were made regarding force limiting launch vehicle environments at low frequencies. Incidentally in the same range where the limiting was applied a launch vehicle mode existed. Furthermore, the telemetry received from the launch vehicle indicated that the rocket exceed its maximum predicted environment in the same range. In this case, when the space vehicle was not able to be contacted on orbit a potential cause for failure was determined to be incorrect notching strategies during vibration testing. Although root cause cannot be positively confirmed,

data that shows which environments the system elements should be tested to will allow all agencies to understand the risk that is being accepted early and develop mitigation strategies if they are required later in the program.

Interface Control Documentation (SV-1, SV-6):

Properly defining and documenting critical system interfaces and agreeing on formats is crucial in the development of component level specifications. Engineering efforts need to be scoped to properly to define, document and socialize critical system interfaces early in the design phase to avoid ambiguity or incompatibility between the various systems. This effort is especially important for systems that are being developed by different stakeholders. In this particular case the ICD needs to be formally signed off to ensure that all invested parties have agreed to the interface. In the design process, this information may be used as catalyst for developing consensus prior to reviews. If developers are required to fully document certain interfaces before certain critical component procurements are initiated pro-activity and inter system dialogue could be forced earlier in the development process.

Interface control documents also need to be reviewed carefully in order to ensure that the proper information is included within the document. In several instances ambiguous references to existing standards have resulted in compatibility problems. Specifically, when selecting command and telemetry data protocols particular information needs to be paid to ensure the view completely demonstrates the planned implementation. In the recent past, references to standards such as CCSDS have given system developers the false security that a format is well understood. A way to eliminate

such ambiguities is to include sample data references in the views that can be reviewed and decomposed by the receiving agency to ensure that a consensus is reached.

PDR Design Presentation (DIV-3, SV-5, OV-6A, SV-10B):

At the culmination of this phase, the initial design for each subsystem and the system as a whole should be well understood. Several aerospace system engineering references such as the Aerospace System Engineering Handbook documents detail all of the pertinent design elements for the various subsystems. However, what is often not seen are common views for how the information should be represented among the various subsystems ensuring that the approach the various developers have for conveying information translates well from subsystem to subsystem. This is not to say that each subs-system needs to be structured identically. However, mandating certain views and information will increase the level of understanding for those who are not intimately familiar with the systems. Discussions with various engineers and program managers identified possible suggestions what these common views may be. They are shown in Table 7.

Technical Performance Budgets (SV-7):

In any development critical performance parameters and limits should be tracked throughout the course of a design. The budgets should be updated at regular intervals in order for all parties to understand how changes to the budget throughout the design process will affect the larger system. The presence of this data should act as a catalyst to assist in understanding if a performance element is at risk and mitigation actions need to be pursued.

Table 7 Recommended Design Review Common Views

Design Specification Information	Purpose
Physical / Functional View	-This view would illustrate all of the components within the system and highlight their functional responsibility within the system as a whole. If the system was software intensive, component references may be less important than identifying the software tasks and their relationship within the system. - This view(s) would also describe the different operating states or modes of the system.
Data Transfer View	Demonstrate how data moves throughout the subsystem/system in both hardware and software. Illustrate the various ways that format is altered in the process.
Reliability Views	- Analysis' showing sub-system reliability and the supporting data/methods implemented - Subsystem and component flight heritage / pedigree - Identify any limited life items within the system to properly identify constraints and risks associated with the development.
Technical Budgets / Performance View	- Identify the system requirements and the expected design performance, demonstrate that design has sufficient margin per industry standards (AIAA) for the given level of maturity - Define the level of analysis/ simulation required to demonstrate the suitability of systems

The views suggested by various SMEs closely resemble the various DoDAF viewpoints for 2.0. This suggests that the recommended views address the different aspects of design from a fairly complete set of perspectives.

4.3.4 Final System Design

At this point in the development a focused effort needs to be made early in the phase to finalize interfaces and resolve any lingering trades. As preliminary designs are accepted, a review of each subsystem needs to be completed before the remaining procurement decisions are finalized and production planning can begin.

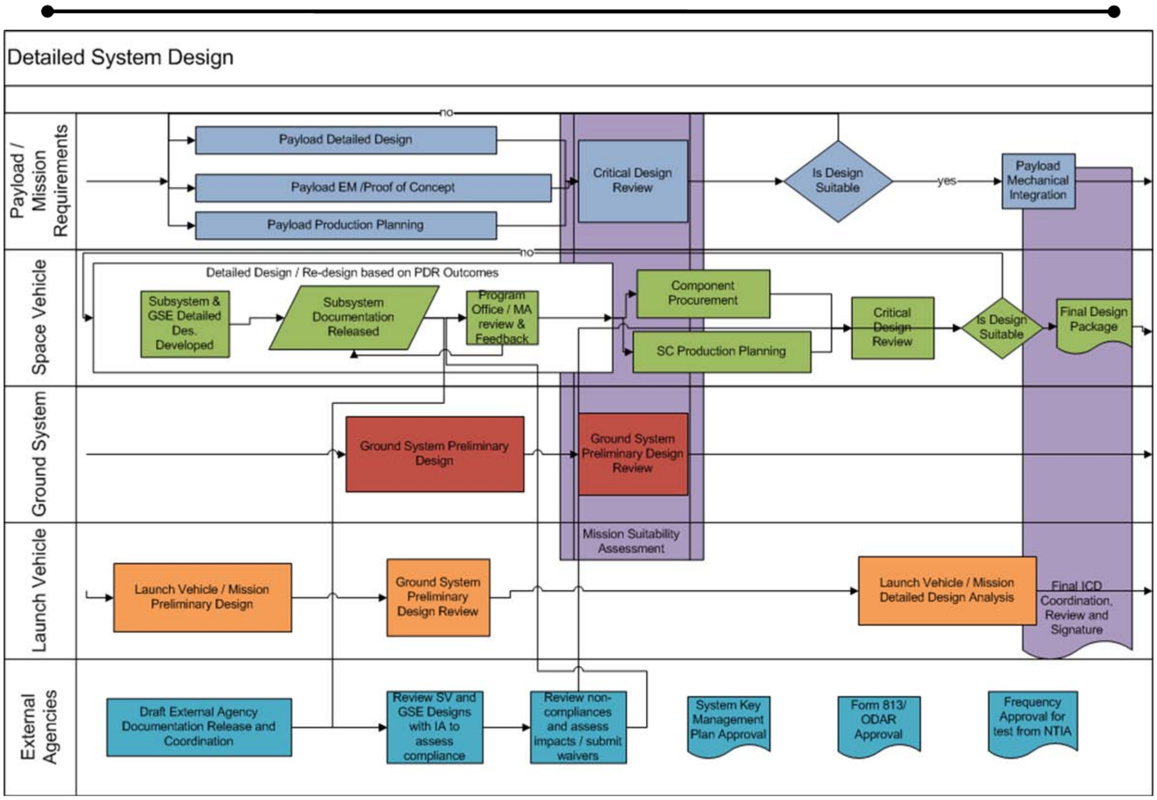


Figure 8 Detailed System Design Process Diagram

Reviews should be thorough, include appropriate stakeholders and mission assurance bodies to ensure effective decisions are made prior to proceeding into a review. In terms of systems architecting, very little new information is recommended at this phase. Instead, the architectural models should act as management tools to ensure the design is has properly matured and open issues are resolved and formal interface agreements have been driven to closure. The table below shows the system architecture framework and maturity that is suggested for this phase.

Table 8 Detailed System Design Architecture Information

Mission Phase	Relevant Architecture Information	Purpose/ Function	Maturity	Product(s)	DODAF Model Reference
Detailed Design					
	System Design Specifications	**- Detailed description of "to be" system/subsystem design - Allocation of required system functions to configuration items - Demonstration of how system requirements are satisfied by design**	Final Delivery	CDR Design Presentation	SV-4 / SV-5
	Integrated Risk List	- Cross functional list of risks compiled across integrated product team	CDR Delivery	Consolidated Risk List	FFP-1A
	Operational Environment	-Matrix documenting how test requirements that have been levied are satisfied with test (at both the component and system levels) - Identification of the method that will be used to verify the requirement - Identification of any potential non-conformances*	Final Delivery	Environmental Test Verification Matrix	FFP-7
	System Interface Control Documentation	**- This will be a suite of documents, the mission plan should identify critical system boundaries that reuqire a formal interface control document - Minimum Criteria: SV - Ground and Payload to SV ICD initial drafts must be complete -Other pertinent ICDs: LV - Spacecraft, Component Interface ICD**	Final Delivery	Interface Control Documentation	SV-1 / SV-6
	Schedule	- Program Driving Schedule Requirements - Key schedule driven technical decisions - Giver /receiver relationships that span different program elements	CDR Delivery	Intgrated Milestone Schedule	PV-2
	Integration Prodcution Plan	**- List of all components under procurement and their expected and need dates - List should include all piece parts, miscellaneous mat'ls, connectors and required ground support equipment**	Initial Delivery	Integrated Production Tracking Tool	FFP-6
	Technical Performance Measures	**- Demonstrate design peformance to critical program requirements outlined within the requirements document**	Final Delivery	Technical performance budget	SV-7
	Open System Trades	- Desription organized by susbsystem of open design trades and decsions that need to be completed - Each trade should have an owner and assocaited due dates that are aligned with program constriants	Living Document	Trade / Decision tracking matrix	FFP-5

In order to do accomplish the goal of closing lingering design decisions in an effective manner, design documentation and models need to be finalized and circulated with stakeholders ahead of the review. Also, for critical interfaces, simulations or test with engineering models should be considered to validate a design. Validation is especially important when considering interfaces among systems that are near the program critical path. The program CDRL and open system trade data models will help assess if this activity has been completed in a timely manner.

In many cases for S&T missions the desire to transition from design to integration rapidly is paramount at this point in the mission. If this is desired, the element of

production planning needs to also be considered at this juncture in the design. In this case, a detailed model that shows how all developmental items will procured, prepared and tested to support planned integration is critical is assessing the validity of the approach for ensuing phases. This plan model should show how all elements both flight and non-flight support the baseline schedule or how they are deficient in order to highlight risk areas to mitigate.

Integrated Production Tracking Tool (FFP-6): Many instances in the development of systems where a small and relatively inexpensive system element causes a significant schedule delay due to unavailability or oversight in the product planning effort. In most instances these issues could have been avoided if tracking tools and methods were used to identify all required parts (including ground support equipment) and track their availability versus need date for system integration. This information will be essential in being able to assess the readiness of a group to transition from design to integration.

4.4 Summary

The use of the process models that depicted the design lifecycle and the DoDAF six step process were both essential parts of developing concepts for an architecture that was relevant for the design of an S&T space system. The ability to have subject matter experts review and discuss the activities within the phase was a catalyst for getting insightful input on the decisions that occur within a given time period and the data required to support them. These lessons translated well into inputs for suggested models and tools for architecture. Additionally, the use of the DoDAF process helped provide a

systematic approach for developing consensus regarding the purpose of the architecture first followed by more detailed discussions regarding the underlying data and views.

In order to provide a more complete description of many of the tailored DoDAF models introduced within this section, Appendix B has a series of model descriptions developed in similar format to the descriptions in Volume II of DoDAF 2.0.

V. Conclusions and Recommendations

5.1 Conclusions of Research

Throughout the course of researching and attempting to propose a systems architecture that would be suitable for a space system development, several general conclusions were reached regarding system architectures and their use as well as specifics insights regarding the suitability of a systems architecture for a space S&T environment.

Architecture needs to be purpose driven. The value of system architecture is not plainly apparent to many and the existence of regulatory guidance will not force architecting to be well aligned with engineering. Unless architecting activities for a given system are given a clear purpose, people may have difficulty identifying how architecture serves a purpose and are immediately useful and applicable. DoDAF V2.0 has come a long way in helping to change the perception of architecture by being data-centric and attempting to re-align system architectures to support the decision making processes within a development. Given the novelty of version 2.0 and the fact that implementation was not completed as a part of this effort questions of supportability and fusion are still largely left unanswered.

Tailoring systems architectures to meet the need of a specific development is equally important. Architecting emerged as a concept that was essential for large interoperable systems that required long-term sustainment and scalability. In the space S&T arena where the long term supportability and interoperability aren't major concerns, an architecture needs to be tailored to address the issues that are relevant to the systems such as managing the complexity and parallel nature of the development, providing tools

and views to help a developer see that the system or group of systems mature appropriately. The flexibility built into DoDAF with composite and "Fit For Purpose" views are aspects of DoDAF 2.0 that have attempted to address this shortcoming and were used extensively in the development of this reference model. However, the use of tailoring also introduces a question regarding scope and relevance of an architecture. The architecture concepts that were addressed in this work were tailored to be satellite centric vs. mission centric and were appropriate for a milestone decision authority that was predominantly focused on a space system. If the reference model was to be extended to encompass the entire mission, there would certainly be other concerns that may change the underlying purpose or goals. In this case, the goals were predominantly developed to support satellite design and development and decision making and were not suitable for larger questions such as assessment of overall mission readiness. This example illustrates that while tailoring an architecture to make it relevant can help solve specific issues, one must ensure that the issues are aligned with what decision authorities and stakeholders expectations and that they understand the limitations of what is being developed.

A systems architecture adopted for this environment needs to be kept simple. Given the finite nature of the missions in a cost overrun or schedule constrained situation, documentation and excess deliverables are always one of the first avenues people look at for relief. However, if the architecture models are well aligned with existing documentation and analyses it seems that two benefits emerge. First, there is little to no effort in producing data or developing product simply for the architecture and second the product is more accurate. Less information is lost or incorrectly translated than if a

second model were produced. As planning and requirements for documentation are created, needs must be clearly conveyed to achieved the desired end result. Ensuring model requirements are conveyed is especially important when mapping program documentation and describing it as a specific DoDAF model. In this case, a concerted effort must be applied to ensure that the data requirements associated with each model do in fact reside in the document and can be extracted. Mapping the product data requirements to the DoDAF data model information in Volume II may result in some additional effort early in the development, but will result in less work than developing and maintaining separate products through the course of the effort.

Finally, accessibility of the information is extremely important regardless of the tools or methods employed. Providing commonly accessible areas where a stakeholder knows how to access the information will bolster the alignment of engineering and architecting. Both the DoD and industry have tools that are available to assist access, and careful review of several options should be completed ensure that they meet given needs prior to selection.

5.2 Significance of Research

One of the most important aspects of a space science and technology demonstration is timeliness. If systems cannot be developed and demonstrated in a timely fashion their applicability is diminished significantly. While schedule performance is very important there is a tenuous balance exists between the approach implemented to accelerate a development and the level technical rigor and required. If system architecting efforts can facilitate timeliness by helping to reinforce decision

making processes and coordinate appropriate technical review, their value would become widely apparent and efforts to refine this would be widely adopted across a wide variety of systems.

5.3 Recommendations for Action / Future Research

This effort was primarily focused on understanding the DODAF models applicability and challenges to space system development leading to version 2.0, how the strategic changes in 2.0 address some of those issues and offering a example of how it could be implemented for a given application (developmental space systems). This effort could be augmented in several useful areas.

Extending the application of this architecture beyond the space element to all of the various systems would provide valuable insight for information that is more relevant to that specific mission area as well as suitability regarding some of the “shared” elements that are described in this architecture. This architecture could also be expanded further in the development process to include integration and test.

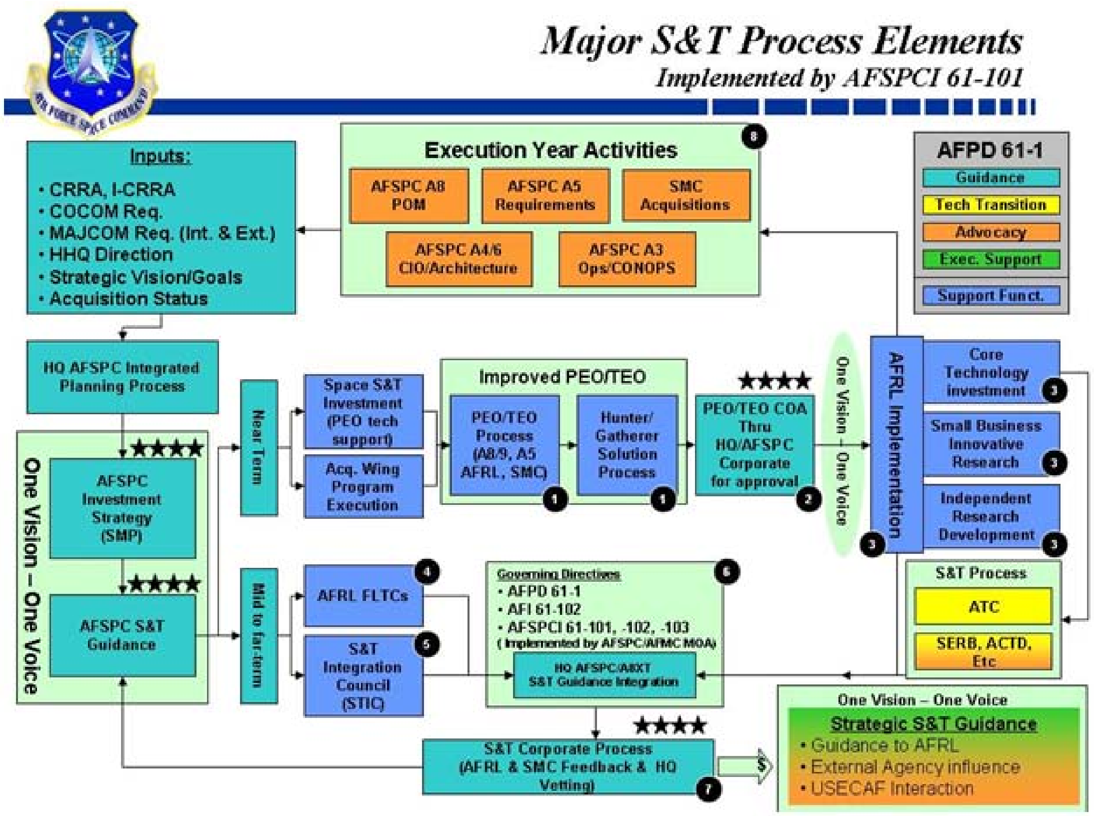
Additionally, the adoption and trial of an architecting effort for a developmental space system would provide important feedback on the applicability of the suggested implementation that has been proposed in this work. Implementing the reference model would also provide useful insight on some of the practical elements of implementation that were not addressed in the scoped in the research.

5.4 Summary

System architecture’s real value lies in its ability to optimize the manner that information is exchanged among system elements in order facilitate development of system as a whole. The method that is used to achieve this is going to be drastically different based on the system, its goals, stakeholders and a number of other factors. In order to make system architecture relevant and useful it needs be tailored to account for this fact. That is not to say each effort is fundamentally different, but it will have unique elements. Additionally, tailoring needs to extend beyond simply what information is gathered in the model. The tailoring process must be more extensively utilized to ask other questions such as how and when the information is gathered. Finally, it must be well aligned with organizational or industry-wide practices for development and documentation so the architecture can be readily adopted.

Appendix A: S&T process Elements Implemented by AFSCI 61-101

The process diagram shown below illustrates the translation of user needs and strategic goals for space into the development of relevant S&T technologies for demonstration.



1. Include robust solution-finding process to support PEO/TEO findings (incorporates concepts from proposed hunter/gatherer process). SMC/CC approved A8/9 as a principal in PEO/TEO
2. Closed-Loop Feedback: Solutions identified by PEO/TEO are approved through S&T corporate process to gain AFSPC/CC approval prior to being implemented by AFRL
3. AFRL implementation leverages a broad set of tools to reduce technology risk or improve schedule/perfomance attributes of required technologies—using them to address PEO/TEO issues in a structured format is new. Some of these implementation options flow through AFSPC S&T process programs. Small Business Innovative Research/Independent Research and Development (SBIR/IRAD) captured in S&T via feedback mechanism
4. AFRL Focus Long Term Challenges (FLTC) address technologies beyond the scope of current developmental engineering plans—this supports HQ AFSPC's long-range plans where SMC has not provided detailed concepts/technology requirements
5. SMC forum to refine technology requirements from the System Program Director (SPD) – supports S&T guidance development at HQ AFSPC. Opportunity to influence more than just the space portfolio
6. S&T Guidance is the integration of all MAJCOM direction into the framework of the Commander's strategic vision and goals, including management and process implementation functions
7. S&T corporate process allows AFSPC/CC intent of HQ vector on all issues sent to external agencies.
8. All existing activities in the command receive feedback and use it in the day-to-day activities

Appendix B: FFP Model Descriptions

FFP-1 (PV) Integrated Risk Plan /List: The integrated risk list is tool that provides the stakeholder with cross functional view of program risk and its effects.

The intended usage of the FFP-1 includes, but is not limited to:

- Program management
- Project planning including financial and schedule planning
- Risk Management
- Schedule Management

Detailed Description:

The Integrated risk list is a program owned and managed model that documents the risk associated with various mission areas.   It is intended to provide program decision authorities with a complete view of risk at any instantaneous point in time. The following elements should be included in the model: full description of the risk, its owner, probability that the risk will be realized, impact if the risk is encountered, risk exposure in terms of cost and schedule, mitigation actions and associated management/ trigger points for re-assessment. This view should be a composite view of the ongoing activities that are occurring to manage risk and provide an understanding of the intermediate events that result in a risk being mitigated or realized.

This should be accompanied by a plan standardizing the way risks will be identified and outlining standard for risk ranking and evaluation. (6)

FFP-2 (SV) Program Documentation Maturity Matrix: This view enables all program stakeholders to understand the various program documents, their intended purpose and how they mature through the course of the program lifecycle.

The intended usage of the FFP-2 includes, but is not limited to:

- Single point of reference for critical program documentation among stakeholders
- Communication tool for system developers
- Common reference point for program information maturity

Detailed Description:

The program documentation maturity matrix is a product that is intended to help facilitate understanding among various system element developers and stakeholders by providing a common location for all major program documentation, a synopsis of the information contained within the document and data regarding how the document is expected to mature throughout the program lifecycle. This model will also denote the information owner and provide contact information. The goal of this model is to assist developers in understanding how relevant information that they may require will mature throughout the program and be a catalyst for communication regarding assumptions of documentation and information contained within. This model will need to be maintained regularly to ensure that the information is accurate.

FFP-3 (SV) Space Vehicle Technical Requirements Document: This model is a comprehensive view of all spacecraft requirements that are levied on the system developed by the acquiring agency. This document contains detailed requirements regarding system and subsystem performance parameter that have been derived from mission requirements.

The intended usage of the FFP-3 includes, but is not limited to:

- A mechanism for providing detailed expectations for system and subsystem standards performance, and testing
- A tool for verification of design suitability for system engineers throughout the development process

Detailed Description:

The space vehicle technical requirements document is a tool for communicating acquiring agency performance expectations to the system developer. This model will enable the acquiring agency to demonstrate how mission requirements have been derived and translate into space segment performance characteristics. The goal of this view is not supersede any mission requirements, but provide the developer specific information regarding government expectations regarding performance, standards, testing and design constraints in order to more clearly present expectations for the system. This should assist the various developers by narrowing the trade space on certain decisions and identify areas of the design where more work is required to achieve requirements compliance.

This information should be provided in a hierarchical format in order to allow developers to understand the relationships of the various requirements to assist verification. If there are specific verification methods that are also required they should be stated within the requirement as well. This information needs to be unequivocal. In other words if it is not

truly required, or the acquiring agency is willing to trade the approach it should be communicated using a different mechanism.

FFP-4 (SV) Requirements Verification Matrix: This model is the developer's response to all of the requirements that have been requested. It is an extension of the technical requirements document that addresses all requirements and how they are satisfied

The intended usage of the FFP-4 includes, but is not limited to:

- Technical Management
- A tool for communicating developer's vision regarding how design requirements will be addressed within the system

Detailed Description:

This model represents the entire requirements set for the system element. It should include all government requirements and properly extend them by providing complete requirements derivation from the component level. The verification matrix should have identified all required functions for the system and allocated them to appropriate sub-system(s).

The model should be developed in an interactive environment that allows the developer and the acquirer to work collaboratively within the construct and facilitate understanding how the requirements are organized and verification methods at the component, sub-system and system levels. There are several different commercial tools and instructions that can be utilized to implement this model.

FFP-5 (SV/PV) Open System Trades: This model provides a mechanism for tracking the progress of various system and subsystem trades throughout a program.

The intended usage of the FFP-5 includes, but is not limited to:

- Program Management
- Systems Engineering
- A tracking tool for the various system developers to identify the ongoing trades that are occurring within a system

Detailed Description:

This model provides an interactive environment for developers to list the carious trades that are occurring within their area of responsibility and communicate how this trade may affect related systems. This tool would also provide the system acquirer insight regarding how the various trades are progressing towards completion within the various stages of the mission design phase. This will provide important verification that due diligence has been completed as procurement decisions occur in parallel with system design. This view should identify the trade and the owner, the related affected parties and should have certain requirements for closure of the trade that extend beyond the responsible engineer for the system. Notation regarding where the outcome of the trade will be documented should be identified. Information regarding the scheduling of the trade should be presented including when the trade was opened, an expected date for completion and an actual date for the closure of the trade. This information will assist the acquiring agency in understanding how the design will mature over time.

FFP-6 (SV/PV) Spacecraft Production Planning Tool

The intended usage of the FFP-6 includes, but is not limited to:

- Program management
- Schedule management and production planning
- Risk Management

Detailed Description:

The space vehicle technical requirements document is a tool for helping to track all of the required materials for integration of the spacecraft including piece parts connectors, facilities and support equipment. The goal of this model is to actively track all parts elements against an integration need date and avoid unnecessary work delay on account of secondary materials being missing.

This model should identify all resources required, their associated need date, anticipated delivery date and whether or not they have been transferred to program inventory. This view should highlight products that either have a short slack or may affect the ability to delay integration. This tool should highlight this information for the user in order to promote early mitigation.

This model should be used for both as an interactive tool for program planning as well as providing a comprehensive insight regarding whether or not the physical resources required for this period have been planned adequately. This model can also be extended

to include other required resources such as procedures and track quantities for parts that may be in short supply or have a limited shelf life.

FFP-7 (SV) Environmental Test Verification Matrix

The intended usage of the FFP-7 includes, but is not limited to:

- Systems Engineering
- Risk Management

Detailed Description:

The environmental test verification matrix illustrates how environmental requirements have been satisfied at the component and system levels. This matrix should include information regarding the qualification method, for each environment, the environments experienced, as well as specific data regarding the repetitions and limits with the associated test.

This view should present a clear picture of if the system has been tested to the expected environments and deviations that may exist. This will allow the systems engineering and risk management personnel to properly assess the risk of system failure during test or launch and early operations.

Appendix C: Subject Matter Expert Survey

How a Tailored Systems Architecture Aides in Decision Making for Space Science and Technology Missions

One of the common questions that is posed when the topic of systems architectures is discussed is ,"what is this for and how does it assist a program?" A commonly cited problem in systems architecting is the divorce between the architecting effort and the decision making that surrounds the program.
The goal of this research is to look at the systems architecture development process (specifically DoDAF 2.0) and determine how it is applicable to systems under development in the Space S&T community.

Historically, the DoDAF process is very thorough and is generally geared to more operational systems that are part of a larger system of systems. In Space S&T acquisitions the finite mission length and fiscal constraints make a traditional DoDAF architecture impractical. Although full systems architecture may not be a feasible, it is my assertion that using a tailored set of architectural views to aid decision making throughout the course of a development may aid missions ensuring that the correct information is available to make appropriate decisions. Additionally, defining the requisite information to make the decision could assist both the developer and the manager in communications and expectation management for the development.
If you have this worksheet I would like to have an informal discussion with you regarding key decisions within a program development. I would like to draw upon your experiences both (positive and negative) regarding key decisions and how they affect space Science and Technology acquisitions. My objective is to look at decisions that profoundly affect a program during the design process, but may not be formally identified as key decision points in the development process. My objective is to sample those examples, critically examine what data would be required to appropriately make the decisions and in turn develop a guide for key system data, products and documentation that is needed during the design process and develop a model for when it should be delivered in the context of a development.
Questions of Interest:

- What decisions have a profound effect on the program that may not be formally tracked or recognized in a program design/development timeline?
    - What are the products/ information required to make the decision?
        - Is the "product" commonly developed or would this be a new product?
    - Are there any recommendations regarding review or signature to increase the awareness of the decisions
    - When in terms of project milestones should the decision and/or data be required?
    - Do you have specific examples of impacts (positive or negative) of how this decision affected the program?
        - Late decisions
        - Decisions made without the appropriate information
        - Deferred decisions
- What do we do right from a decision making standpoint?

What are good examples of situations where we make sound decisions based on data presented in a timely fashion?

Appendix D: Proposed S&T Architecture Framework

Mission Phase	Relevant Architecture Information	Purpose/ Function	Maturity	Product(s)	DODAF Model Reference	Notes:
Pre - system Acquisition						
	Integrated Risk List	**- Cross functional list of risks compiled across integrated product team**	Living Document	Consolidated Risk List	FFP-1A	
	Integrated Risk Plan	**- Documentation outlining the program's risk posture and threshold's for reporting and mitigating risk**	Initial Delivery	Consolidated Risk Plan	FFP-1B	
	Schedule	**- Program Driving Schedule Requirements - Key schedule driven technical decisions - Giver /receiver relationships that span different program elements**	Living Document	Integrated Milestone Schedule	PV-2	
	Critical System Requirements Capabilities / Constraints / Outcomes	**- Identify required program outcomes / measures of effectiveness - How residual capability may be used if deemed successful - Communicate aspects of the mission that must be adhered to and cannot be traded within the project**	Initial Delivery	Mission Plan	AV-1	
	Organizational Roles / Boundaries	**- Establish lines of authority - Highlight system boundaries that will require interface control documentation to be developed - Delegate project roles and responsibilities**	Initial Delivery	Mission Plan	OV-1 OV-4	
	Design Standards and Life Requirements	**- List of regulatory standards that program is required to comply with - Understanding of nominal SC design life and risk classification (i.e. Class A, B, C...) - List of any international treaties that may affect program decisions - List of applicable technical standards**	Initial Delivery	Mission Plan	STDV-1	
	Critical Program Documentation	**- Identify required documentation/ information /models from various system developers - Highlights the how many iterations are planned throughout the document lifecycle - Identifies delivery dates for all information among stakeholders**	Living Document	Program Documentation Maturity Matrix	FFP-2	Note 1: This needs to be a consolidated government owned product that is inclusive of all mission areas
	Open System Trades	**- Description organized by subsystem of open design trades and decisions that need to be completed - Each trade should have an owner and associated due dates that are aligned with program constraints**	Living Document	Trade / Decision tracking matrix	FFP-5	
Concept Refinement						
	Integrated Risk List	- Cross functional list of risks compiled across integrated product team	Living Document	Consolidated Risk List	FFP-1A	
	Schedule	- Program Driving Schedule Requirements - Key schedule driven technical decisions - Giver /receiver relationships that span different program elements	Living Document	Intgrated Milestone Schedule	PV-2	
	Critical System Requirements Capabilities / Constraints / Outcomes	- Identify required program outcomes / measures of effectiveness - How residual capability may be used if deemed successful - Communicate aspects of the mission that must be adhered to and cannot be traded within the project	Final Delivery	Mission Plan	AV-1	
	Organizational Roles / Boundaries	- Establish lines of authority - Highlight system boundaries that will require interface control documentation to be developed - Delegate project roles and responsibilities	Final Delivery	Mission Plan	OV-1 OV-4	
	Required Standards, Design Life Requirements	- List of regulatory standards that program is required to comply with **- Includes Preliminary LV Environments and Loads** - Understanding of nominal SC design life and risk classification (i.e. Class A, B, C...) - List of any international treaties that may affect program decsions - List of applicable technical standards	Final Delivery	Mission Plan	STDV-1	This should be coordinated w/ external agencies to ensure completeness
	Requirements Functionally allocated and derived for each subsystem and component	**- System Developers repsonse to the Technical Requirements Document - Identifies how requirements will be allcoated among various systems - Highlights functional responsibility for each subsystem - Provides critical data regarding system boundaries and interfaces**	Final Delivery	SV Requirments Specification	FFP-4	Typically delivered leading up to SRR / reference DISA DID
	SV Technical Requirements Documentation	**- Complete list of performance requirements for the Space System - Delivered by the government to the contractor / agency responsible for space vehicle design, development and integration**	Initial Delivery	SV Technical Requirements Document	FFP-3	
	Open System Trades	- Description organized by subsystem of open design trades and decisions that need to be completed - Each trade should have an owner and associated due dates that are aligned with program constraints	Living Document	Trade / Decision tracking matrix	FFP-5	

Mission Phase	*Relevant Architecture Information*	*Purpose/ Function*	*Maturity*	*Product(s)*	*DODAF Model Reference*	*Notes:*
Preliminary System Design						
	Integrated Risk List	- Cross functional list of risks compiled across integrated product team	PDR Delivery	Consolidated Risk List	FFP-1A	
	Operational Environment	**-Matrix documenting how test requirements that have been levied are satisfied with test (at both the component and system levels) - Identification of the method that will be used to verify the requirement - Identification of any potential non-conformances***	Initial Delivery	Environmental Test Verification Matrix	FFP-7	This will show the capability of the SV to withstand various environments (i.e. launch vehicles)
	System Interface Control Documentation	**- This will be a suite of documents, the mission plan should identify critical system boundaries that reuqire a formal interface control document - Minimum Criteria: SV - Ground and Payload to SV ICD initial drafts must be complete -Other pertinent ICDs: LV - Spacecraft, Component interface ICD**	Initial Delivery	Interface Control Documentation	SV-1 / SV-6	
	Schedule	- Program Driving Schedule Requirements - Key schedule driven technical decisions - Giver /receiver relationships that span different program elements	Living Document	Intgrated Milestone Schedule	PV-2	
	System / Sub-system Design Specifications	**- Partial Preliminary understanding of system/subsystem design - Allocation of required system functions to configuration items - Demonstration of how system requirements are satisfied by design**	Initial Delivery	PDR Design Presentation	SV-5	
	Open System Trades	- Desription organized by susbsystem of open design trades and decsions that need to be completed - Each trade should have an owner and assocaited due dates that are aligned with program constriants	Living Document	Trade / Decision tracking matrix	FFP-5	
	Technical Performance Measures	**- Demonstrate design peformance to critical program requirements outlined within the requirements document**	Initial Delivery	Technical performance budget	SV-7	Values in the budget should be compared to industry standards for a given maturity in the devleopment
Detailed Design						
	System Design Specifications	**- Detailed description of "to be" system/subsystem design - Allocation of required system functions to configuration items - Demonstration of how system requirements are satisfied by design**	Final Delivery	CDR Design Presentation	SV-4 / SV-5	Note: Reference Lesson 11 - Need to look at some views and diagrams that would be useful for every subsystem
	Integrated Risk List	- Cross functional list of risks compiled across integrated product team	CDR Delivery	Consolidated Risk List	FFP-1A	
	Operational Environment	-Matrix documenting how test requirements that have been levied are satisfied with test (at both the component and system levels) - Identification of the method that will be used to verify the requirement - Identification of any potential non-conformances*	Final Delivery	Environmental Test Verification Matrix	FFP-7	Note: previous delivery should have defined how requirements would be satisfied for long lead components. This delivery would address all remaiing compents and system levels
	System Interface Control Documentation	**- This will be a suite of documents, the mission plan should identify critical system boundaries that reuqire a formal interface control document - Minimum Criteria: SV - Ground and Payload to SV ICD initial drafts must be complete -Other pertinent ICDs: LV - Spacecraft, Component Interface ICD**	Final Delivery	Interface Control Documentation	SV-1 / SV-6	
	Schedule	- Program Driving Schedule Requirements - Key schedule driven technical decisions - Giver /receiver relationships that span different program elements	CDR Delivery	Intgrated Milestone Schedule	PV-2	
	Integration Prodcution Plan	**- List of all components under procurement and their expected and need dates - List should include all piece parts, miscellaneous mat'ls, connectors and required ground support equipment**	Initial Delivery	System Parts List	FFP-6	
	Technical Performance Measures	**- Demonstrate design peformance to critical program requirements outlined within the requirements document**	Final Delivery	Technical performance budget	SV-7	Values in the budget should be compared to industry standards for a given maturity in the devleopment
	Open System Trades	- Desription organized by susbsystem of open design trades and decsions that need to be completed - Each trade should have an owner and assocaited due dates that are aligned with program constriants	Living Document	Trade / Decision tracking matrix	FFP-5	

Appendix E: Acronyms

AFI	Air Force Instruction
AFRL	Air Force Research Laboratory
AFSPC	Air Force Space Command
AFSPCI	Air Force Space Command Instruction
C4ISR	Command, Control, Communications, Computers, Surveillance and Intelligence Architecture Framework
CDRL	Contract Deliverable Requirements List
COTS	Commercial " Off the Shelf"
DID	Data Item Description
DoD	Department of Defense
DoDAF	Department of Defense Architecture Framework
MIL-STD	Military Standard
SE	Systems Engineering
SGLS	Space -Ground Link System
S&T	Science And Technology

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Vita

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14. ABSTRACT

The use of systems architecture, following a set of integrated descriptions from an architecture framework, has been well codified in Department of Defense acquisition and systems engineering. However, in the Space Science and Technology (S&T) community, this guidance and practice is not commonly adopted. This paper outlines an approach to leverage the changes made in DoD Architecture Framework 2.0 (DoDAF2.0), and the renewed emphasis on data and support to acquisition decision analysis. After decomposing the Space S&T design lifecycle into phases, design milestones and activities using process models, a set of DoDAF prescribed and Fit-for-Purpose views are constructed into a reference implementation of a system architecture. This approach attempts to make DoDAF2.0 more relevant and integrated with S&T missions and the decisions that are encountered.

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